LBNL

Superconducting Magnet Program

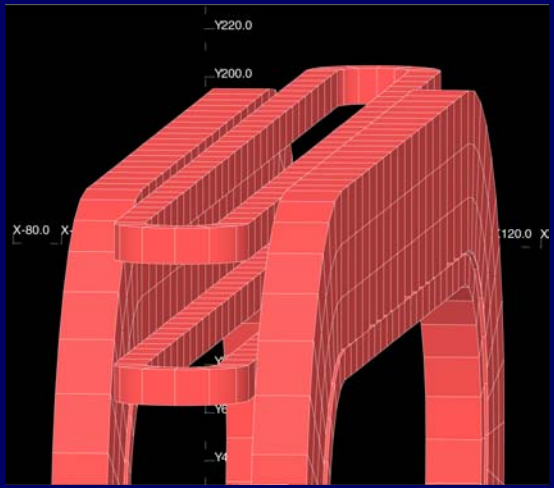
DOE/HEP Review

May 29, 2003

Stephen A. Gourlay

Superconducting Magnet Program

- Program Overview
  - Mission and Philosophy
  - History
  - Conductor and Materials
  - Magnets



- Technical Progress, Current Status
- Budget and Staff Update
- Summary

Mission and Philosophy

- Accelerator Magnet Program emphasizing development of new technology for HEP
  - Issue-driven accelerator magnet program
  - Explore parameter space and challenge existing limits
    - High fields/gradients
    - Accelerator quality
    - Aperture
    - Training
    - Cost effective designs

"conservatism is not our style"

HEPAP Recommendations

- 2001
  - "... high priority to accelerator R&D because it is absolutely critical to the future of our field".
    - LBNL has been developing enabling technology for HEP for over 20 years
  - "High-field magnet research is particularly important"
    - LBNL has produced record breaking fields in two different geometries
    - No program has built more magnets with fields exceeding 10 Tesla
    - LBNL leadership of the LARP Magnet Program (S. Gourlay)
    - LBNL leadership of the DOE/HEP Conductor Development Program (R. Scanlan)
  - "efforts should be made to form an international collaboration as early as possible".
    - LBNL-sponsored international workshop on "Magnets beyond NbTi" (3/17-18/03)
    - Participation in ESGARD (European Steering Group on Accelerator R&D)

History of Program Contributions

NbTi Technology

- SSC
  - First 40 mm dipole prototypes
  - Quad prototypes (1m and 5m)
  - Materials and cable development
  - D19
    - **World Record Dipole field of <u>10.15 T</u>**
    - **50 mm aperture SSC prototype**
- LHC
  - Cable for IR quads
  - IR quad design
  - DFBX components

Nb_3Sn Technology

- Cosθ geometry
  - D19h – Nb_3Sn/NbTi hybrid
  - D20
    - **World record dipole field of <u>13.5 T</u>**
    - **50 mm aperture**
- Racetrack geometry
  - Common coil
    - **6 T, 12.2 T, 10 T**
    - **World record dipole field of <u>14.5 T</u>**
  - "H" geometry
    - **> 15 T (This summer)**

Superconducting Magnet Program

Full spectrum development program for superconducting magnet technology

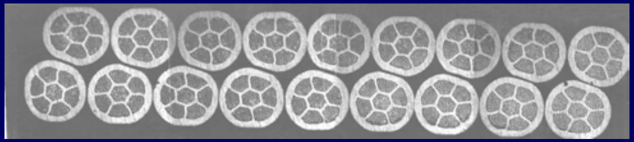
Materials and Conductor → Magnets

- More than two decades at the forefront of magnet technology
  - Our program maintains continuity
    - **Driven by HEP, not lab priorities**
  - Opportunity for innovation – not just an iteration of what was done before
- Strong interactions with industry, labs and universities
  - Exceptional record in materials development with industry
    - **DOE/HEP Conductor Development Program**
    - **SBIR's**
    - **Organizer and sponsor of Low Temperature Superconductor Workshop**

SC Materials and Cable Development

State of the art cabling facility to support HEP technology programs

- Lead Lab for DOE Conductor Development Program
  - Significant progress on Nb_3Sn J_C
    - 50% increase in 3 years
    - ~ 3,000 A/mm^2 at 12 T and 4.2 K
- LHC High Gradient Quad Cable
  - NbTi cable for FNAL completed 2-02
  - Fully keystoned Nb_3Sn for LHC upgrade
- Cable R&D
  - Explore the limits of Rutherford-type cables
    - New techniques
    - New Materials (HTS)



Conductor Development Program Priorities

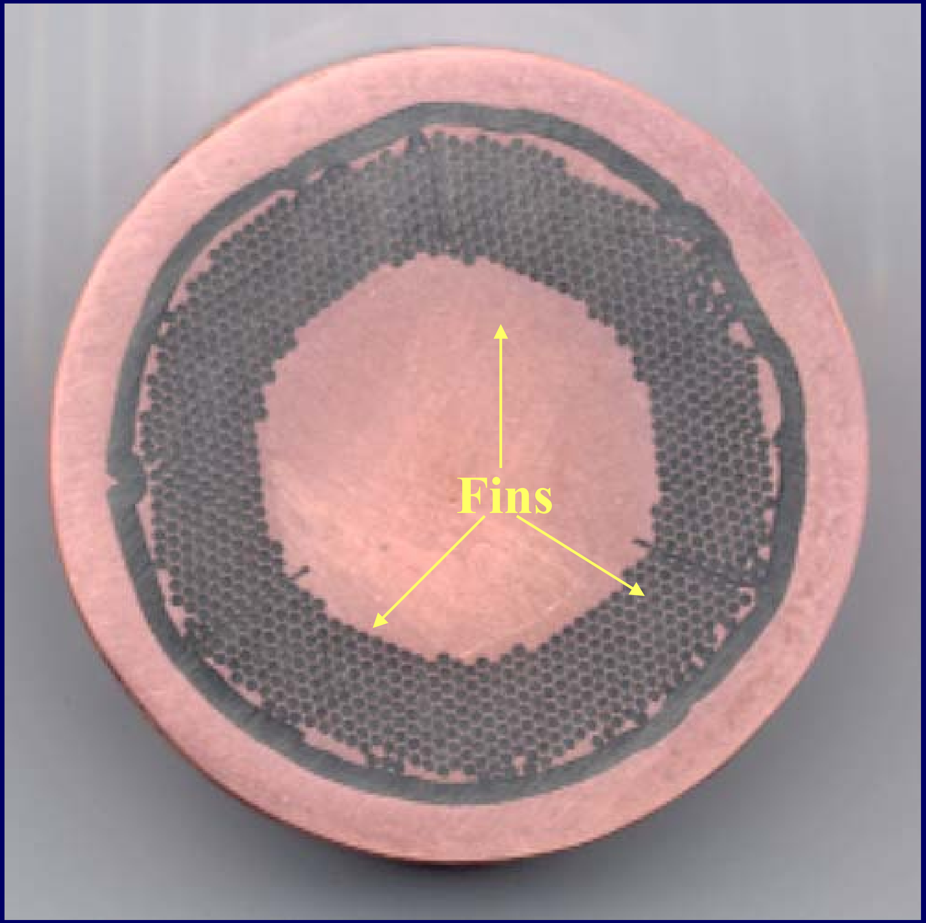
FY03

OST

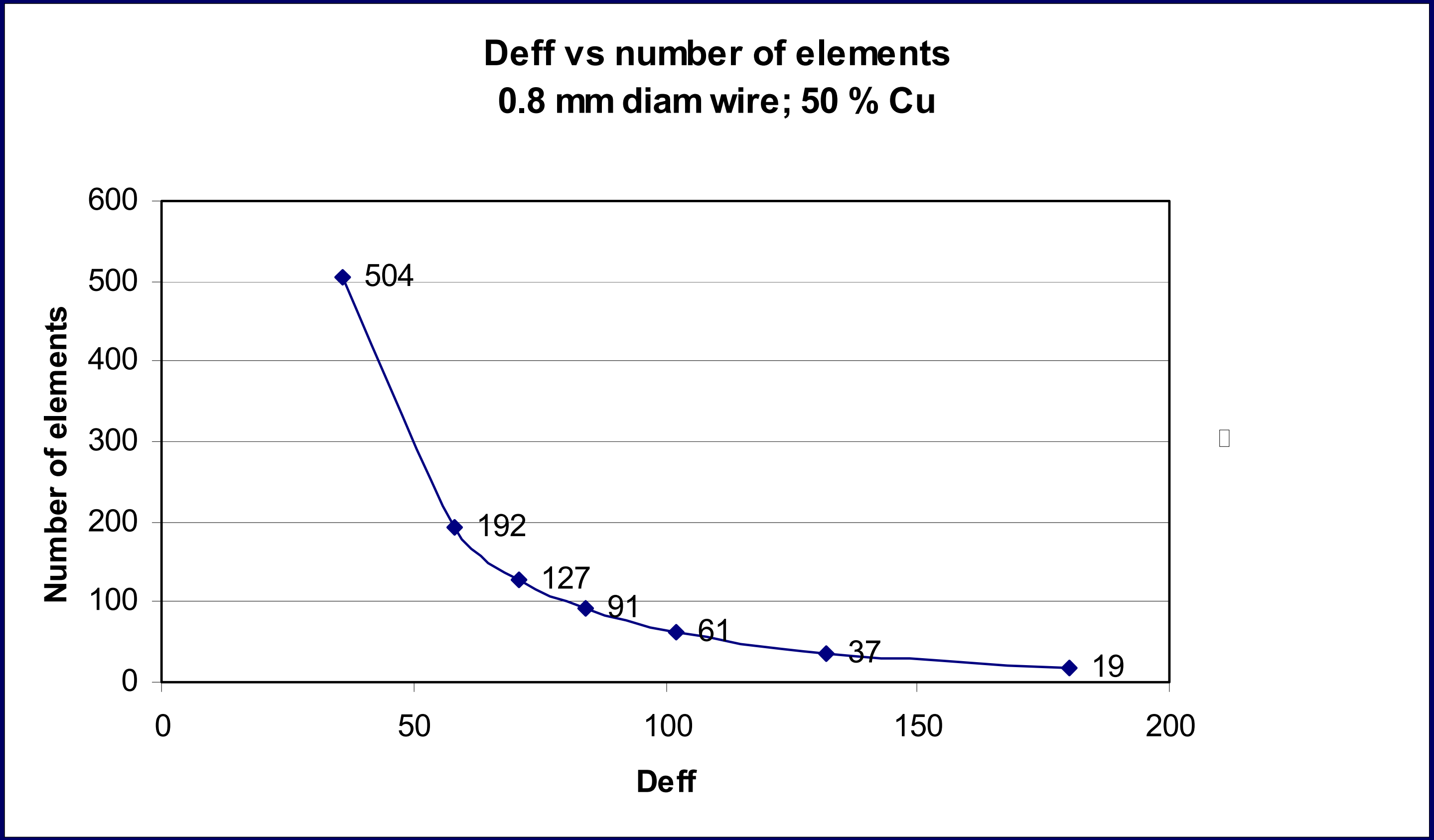
- Reduce D_{eff} from 120 to 50 microns
- Improve diffusion barriers to increase Cu RRR
- Scale up HER (Hot Extruded Rod) billet size

OKAS

- Reduce D_{eff} from 120 to 50 microns with internal fins



Low D_{eff} in high J_c Nb_3Sn



Fundamental issue is restacking large numbers of subelements

Collaborations and Community Service

- SC Materials and Cable
  - Fermilab Nb_3Sn program (W&R, R&W)
  - Texas A&M Nb_3Sn Program
  - BNL Nb_3Sn/HTS
  - U. Twente Powder-in-Tube Nb_3Sn
  - Insulation development w/ CTD and MCT (SBIR Programs)

- Community Contributions
  - ASC
  - Snowmass
  - CEC/ICMC
  - MT-18
  - MuTAC
  - DOE/SBIR Reviews
  - PAC
  - HEP/LTSW Organizers
  - WAAM Organizers

  (Workshop on Advanced Accelerator Magnets)
  - Technical Review Committees

Every year our program contributes more than $300k in services to other programs

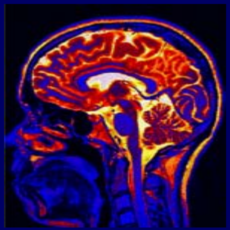
LDRD

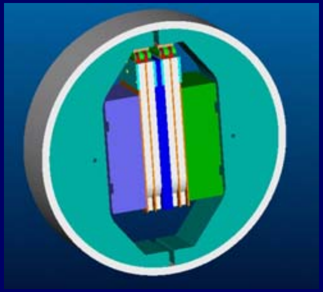
Exploring the limits of technology for new applications

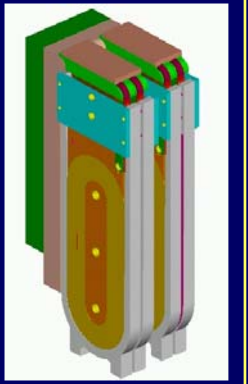
Ex-Situ MRI –

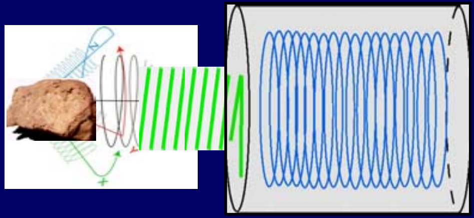
G.L. Sabbi, P. Ferracin, S. Bartlett

NMR and MRI outside the magnet





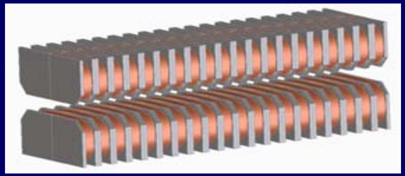


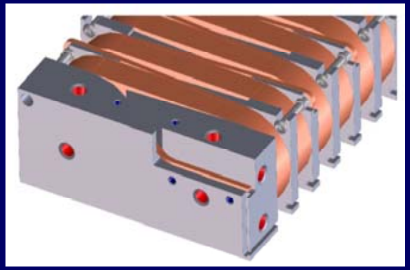


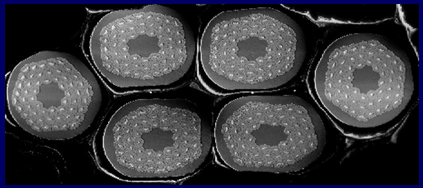
Superconducting Undulator –

D. Dietderich and S. Prestemon (ED)

High fields and short periods are required for advancing the field

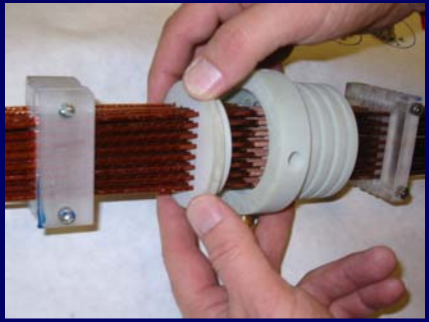






Work-For-Others and Tech Transfer

- LHC
  - Emergency correction coil cable run
    - Completed in April
  - LHC Feedboxes (DFBX)
    - Lambda plug fabrication



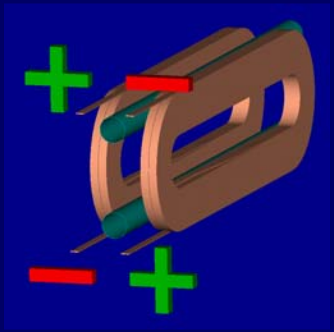
- Showa Electric
  - Bi-2212 Cable

- Quad test for Fusion Program

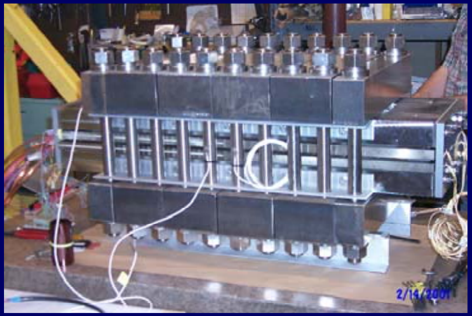
- Sub-scale magnet technology for Fermilab

Common Coil Magnets at LBNL

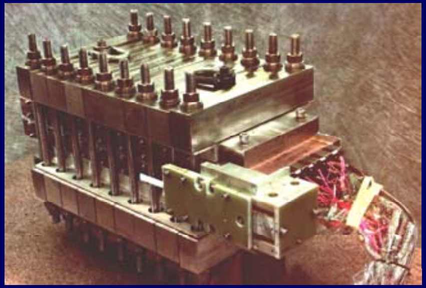
- **High Field**
- **Field Quality**
- **Simple Fabrication Techniques**



10.9 Tesla
RD3-c

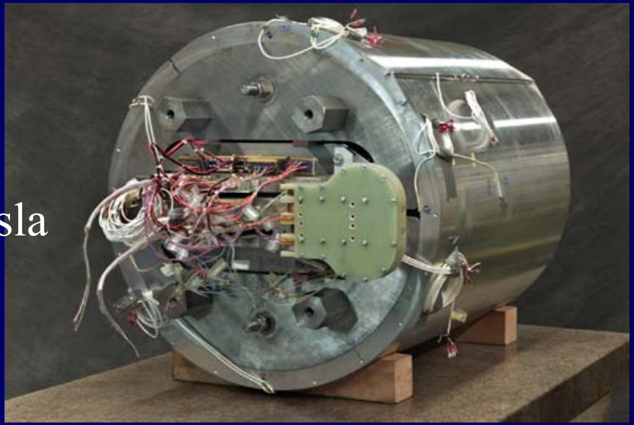


12 Tesla
RT1



6 Tesla
RD2

12 Tesla
SM-01

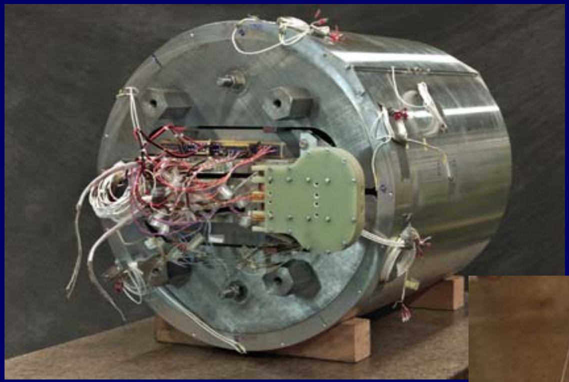


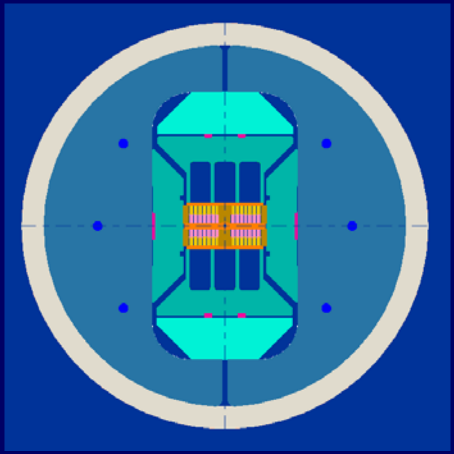
14.5 Tesla
RD3-b

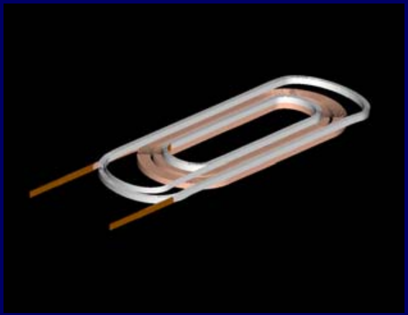
Magnet Development

Fully Integrated Program

- Field quality design options
  – RD Series
- New geometries for high field
  – HD-Series
- Technology Development
  – Sub-scale model program (SM)

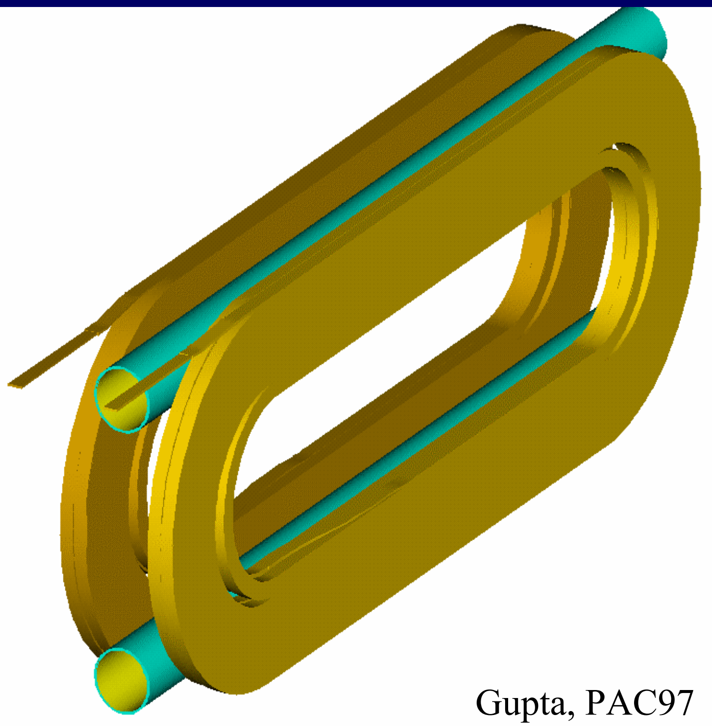






RD Series: Common Coil Layout

A new design paradigm aiming at conductor compatibility and cost reduction



Gupta, PAC97

Advantages:

- *Large end radius*
- *Flat cable*
- *High packing in small aperture*
- *Simpler support structure*

Challenge:

Incorporate accelerator quality while maintaining simplicity

RD3c Objectives

For the first time in a common coil dipole:

1. Demonstrate central geometric harmonics at 10^{-4} level in a 35 mm bore
2. Perform measurements of other relevant geometric and dynamic effects
3. Compare experimental data with calculated values

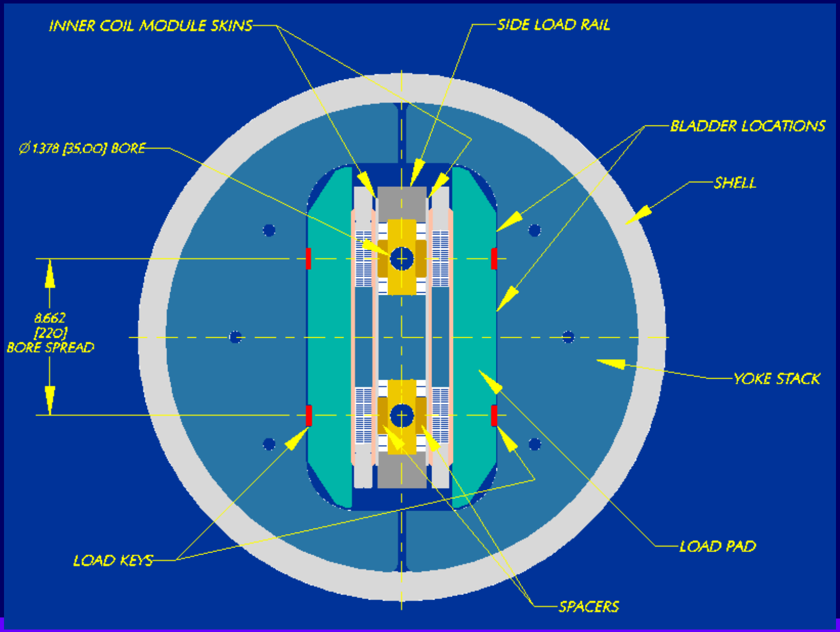
Simple coil configuration:

- RD3B Outer Modules
- New, RD3B-type inner module

Geometric field quality features:

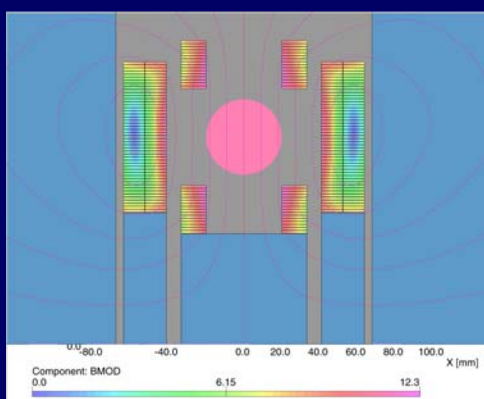
- Auxiliary (pole) turns
- Central spacer

Design field: 10.9 T



RD3c Magnetic Design

Coil geometry



Field at the probe

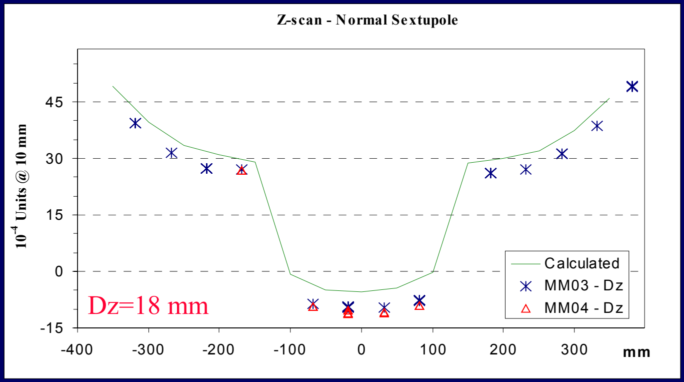
RD3c Test Results: Field Quality

Central harmonics

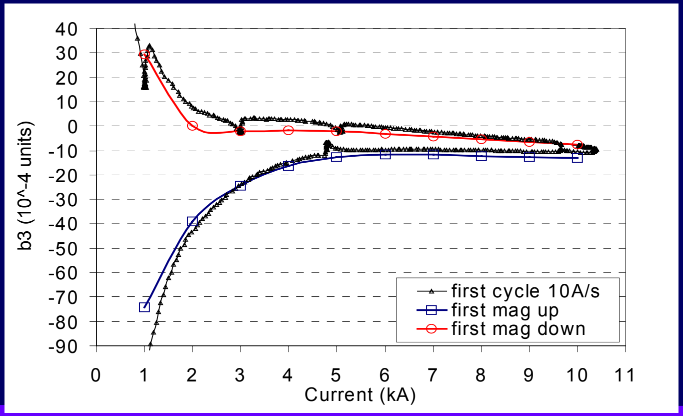
Normal	calculated	measured
b_3 (unit)	-5.44	-10.39
b_5 (unit)	-0.24	-0.02
b_7 (unit)	0.58	0.61
b_9 (unit)	<0.01	<0.01

I_{op}=10 kA, R_{ref}=10 mm

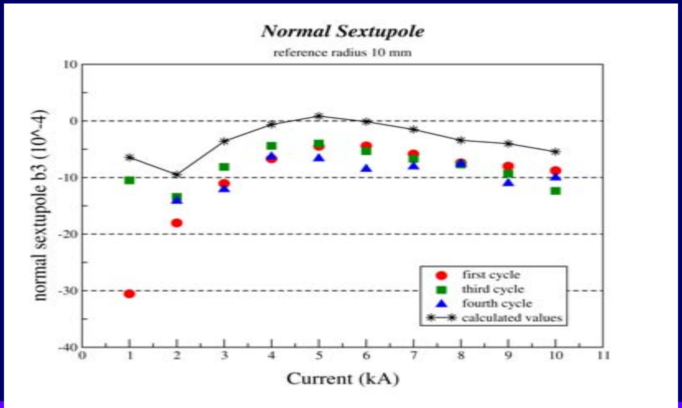
End Field



Magnetization – Eddy Currents



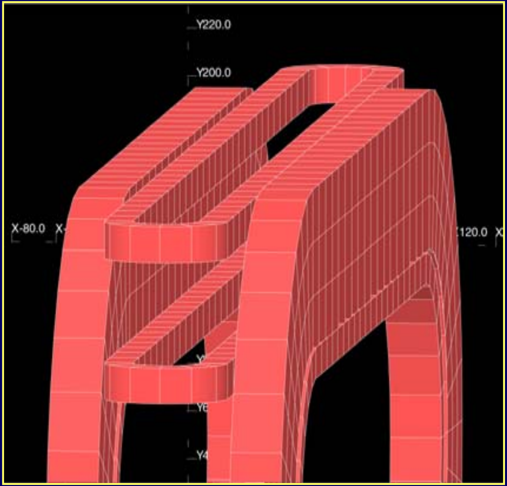
Iron Saturation



RD Series: Next Steps

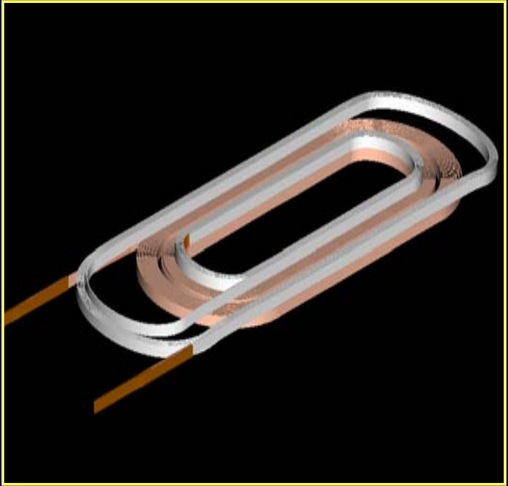
RD3D

- Single layer aux. coils
- End optimization
- 10^{-4} geom. harmonics
- 11 T, 40 mm clear bore



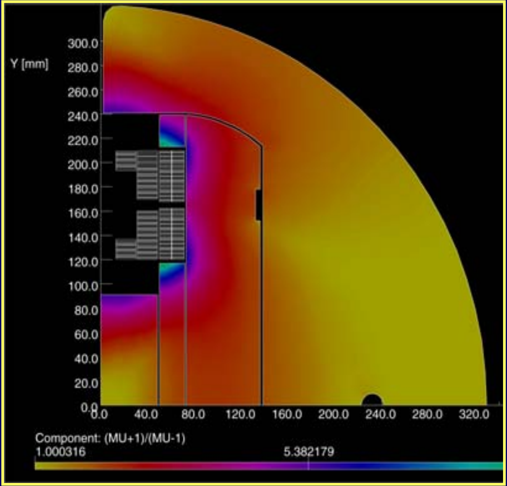
RD4

- Two-layer inner module
- Flared ends for aperture
- 10^{-4} geom. harmonics
- 13 T, 40 mm clear bore



RD5

- Four layers, flared ends
- 10^{-4} geometric, end harm.
- Saturation, magnetization
- 15 T, 40 mm clear bore

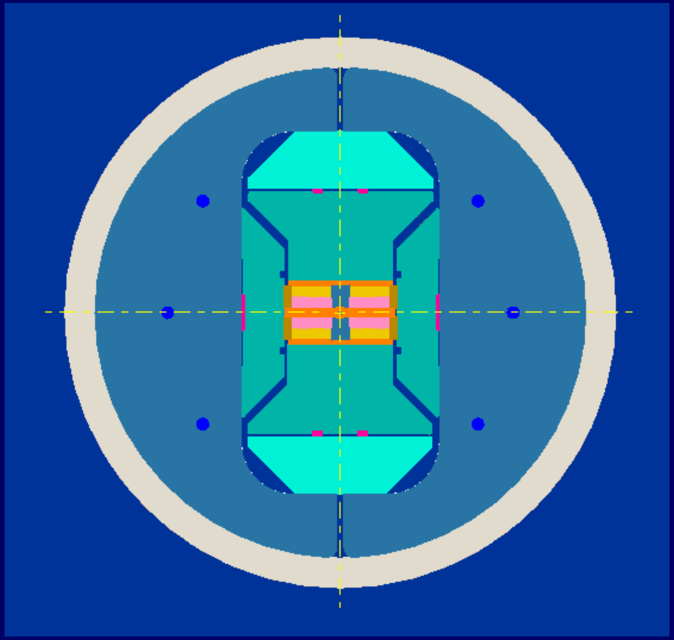


HD Series: 15–18 Tesla

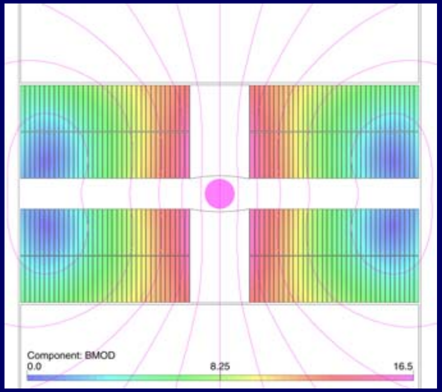
New High Field Dipole Test Configuration

Design Features:

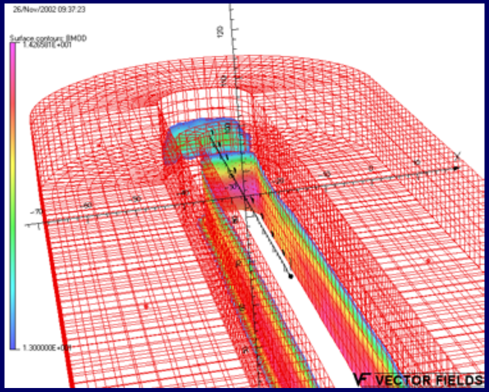
- Single bore
- Two flat double pancakes
- Horizontal configuration
- Dipole field 15-18 T



Magnet cross-section



Coil cross-section

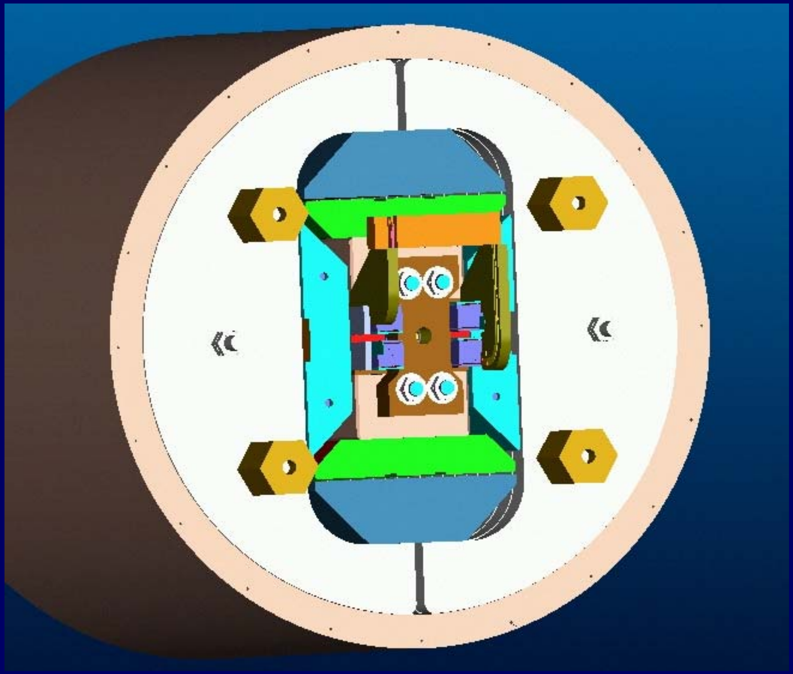


Coil end field

Next Step: HD1 Dipole

Goal (and challenge):

In one step, new coil configuration and new field record: 15+ T



SHORT SAMPLE PARAMETERS

Parameter	Unit	HD1	RD3B
$B_0^{(ss)}$	T	16.2	14.5
$I^{(ss)}$	kA	10.5	10.8
B_{max}	T	15.6	14.8
$J_{cu}^{(ss)}$	kA/mm^2	1.2-1.4	1.1/1.5

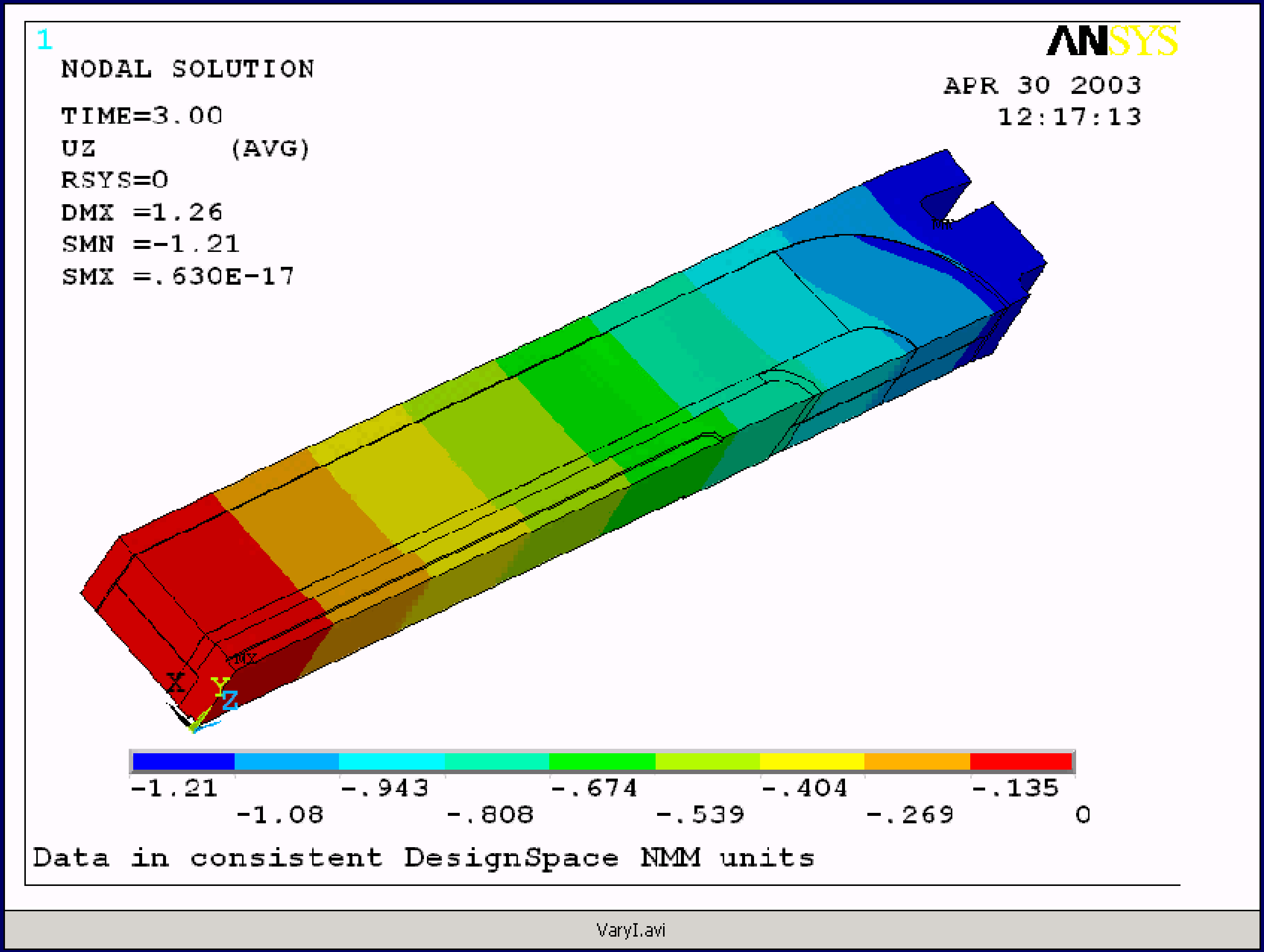
Status:

Coils in reaction oven

Test in August

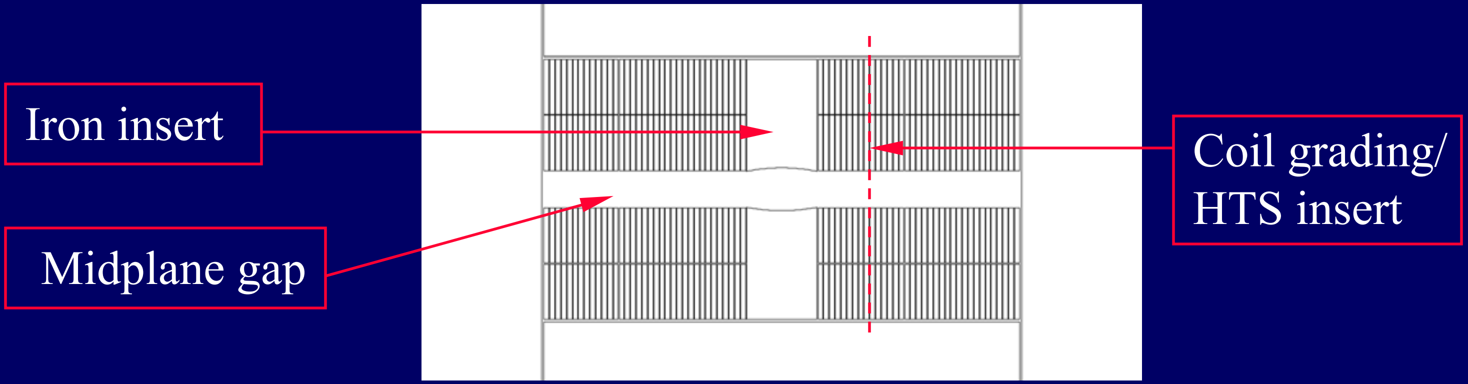
Full 3D Analysis

- Magnetic
- Thermal
- Structural
- Electrical



HD Series: High Field

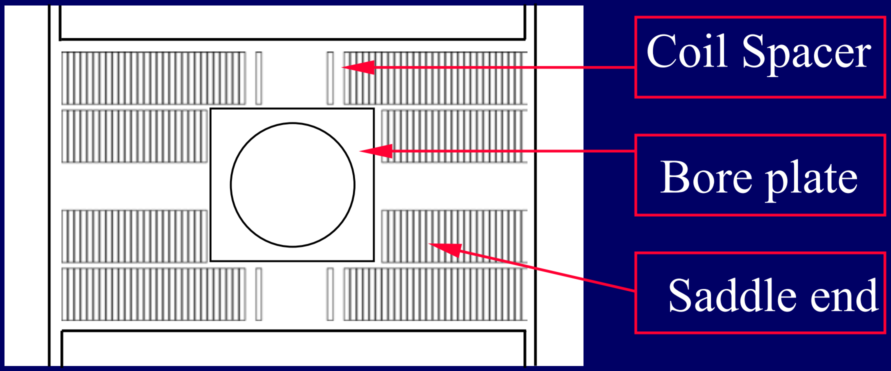
Design features	Dipole field (T)	Iss (kA)
HD1 reference	16.2	10.5
RD3B conductor	15.3	10.0
Nb_3Sn graded coil (8 turns half density)	17.5	14.0
HTS insert 7 turns 0.8 mm 361 A @ 18 T	18.6	13.0



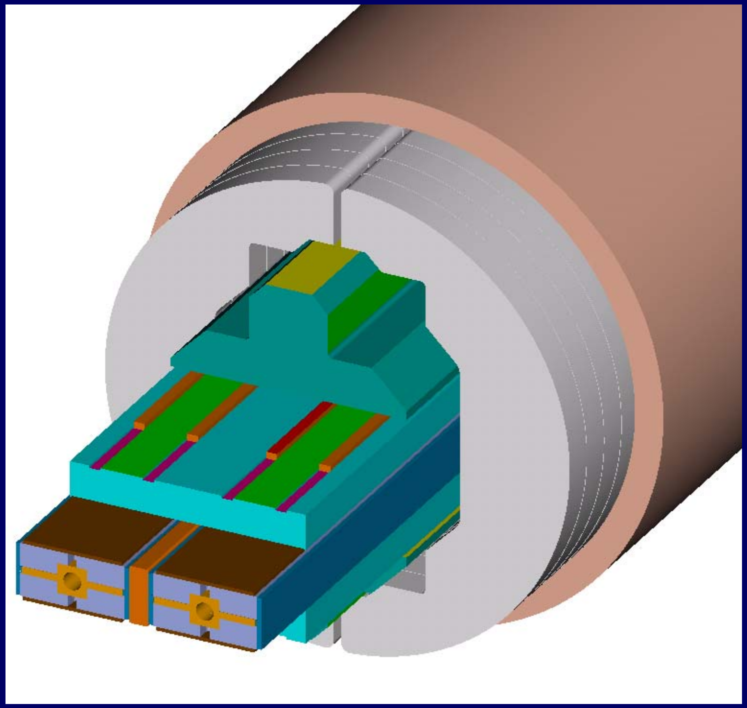
HD Series: Accelerator Quality

Design issues (and priority):

1. Saddle ends for efficiency
2. Clear bore size and support
3. Spacers & field quality



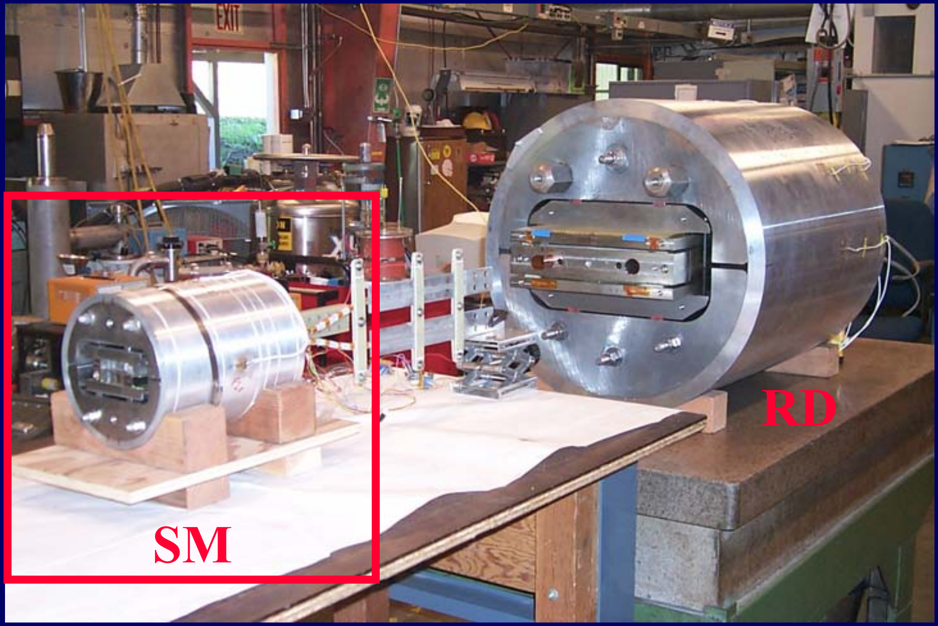
Dual bore configuration: Super LHC?



SM Series: Subscale Prototypes

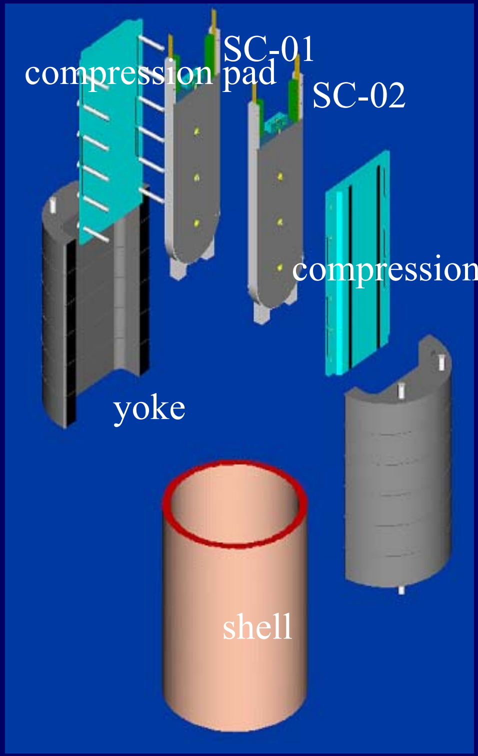
Technology Development with Fast Turnaround

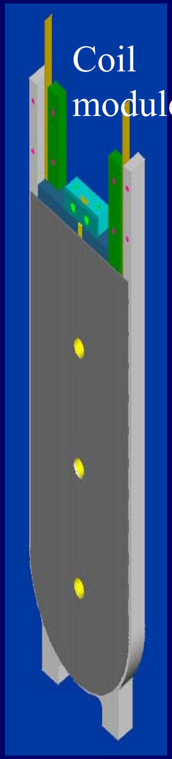
- Scaled version of main magnet
  - Approx. 1/3 scale
- Field range of 9 – 12 Tesla
- Two-layer racetrack coils
  - 5 kg of material per coil
- Streamlined test facility
  - Small dewar
  - Basic instrumentation



First mechanical test demonstrated bladder & key assembly for RD3

SM Magnet Features





Two layer coil

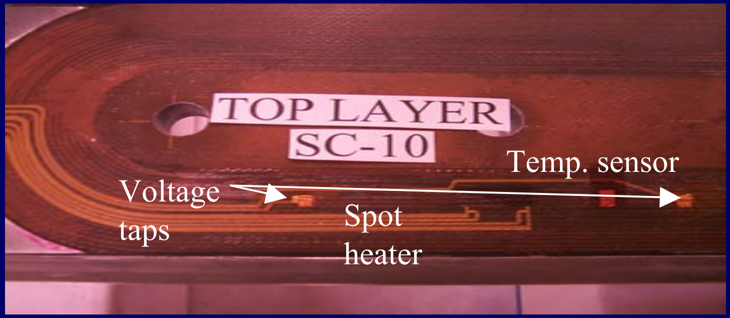
Assembled Magnet

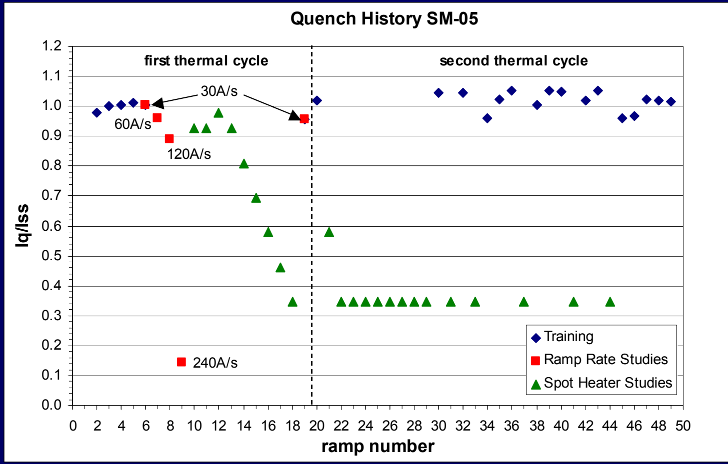
Modular, reusable components

SM Prototypes 2002-2003

- SM-02 (July 2002)
  - Mixed-strand
  - Low quench performance
- SM-03 (October 2002)
  - Mixed-strand
  - Better performance than SM-02
- SM-04 (October 2002)
  - CTD/FNAL Ceramic Insulation
  - Excellent performance
- SM-05 (March 2003)
  - Stress/temperature limits
  - Excellent performance

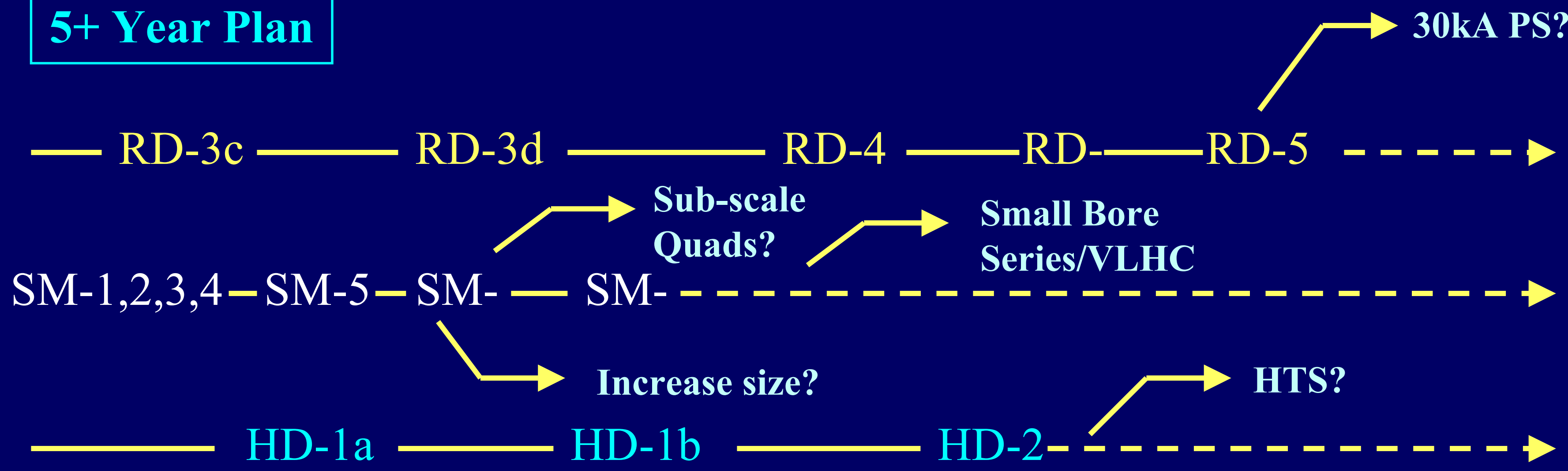
SM05 Test: peak temperature 600 K





R&D Program Tree (RD, HD, SM)

5+ Year Plan



FY02 | FY03 | FY04 | FY05 | .....

At the same time, we are working to add new program components

LHC Luminosity Upgrade

Second-generation Nb_3Sn IR Quadrupoles

Assuming J_c (12T, 4.2K) = 3 kA/mm^2 T_{op}=1.9K

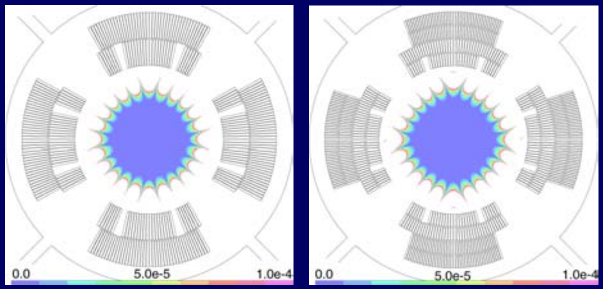
Maximum gradient	Conductor peak field
• 260 T/m (2-layer)	• 13.3 T (2-layer)
• 285 T/m (4 layer)	• 14.4 T (4 layer)

- Will extend the discovery potential of LHC

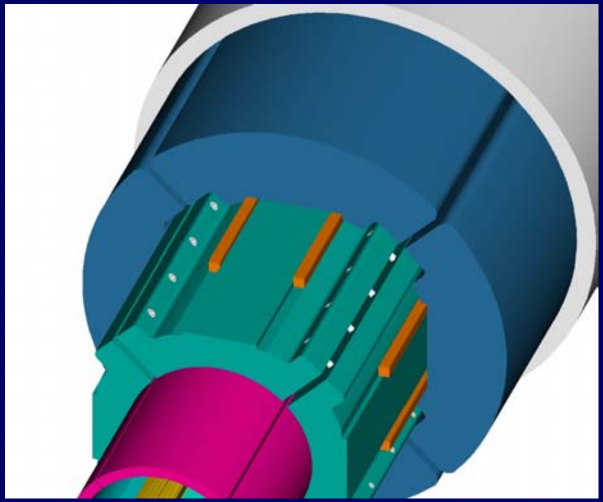
- Key contribution of the LBNL Program:

Successful LBNL prototype tests demonstrated the feasibility of the LHC luminosity upgrade

- Leadership role



Two or four layer designs



Bladder and key assembly

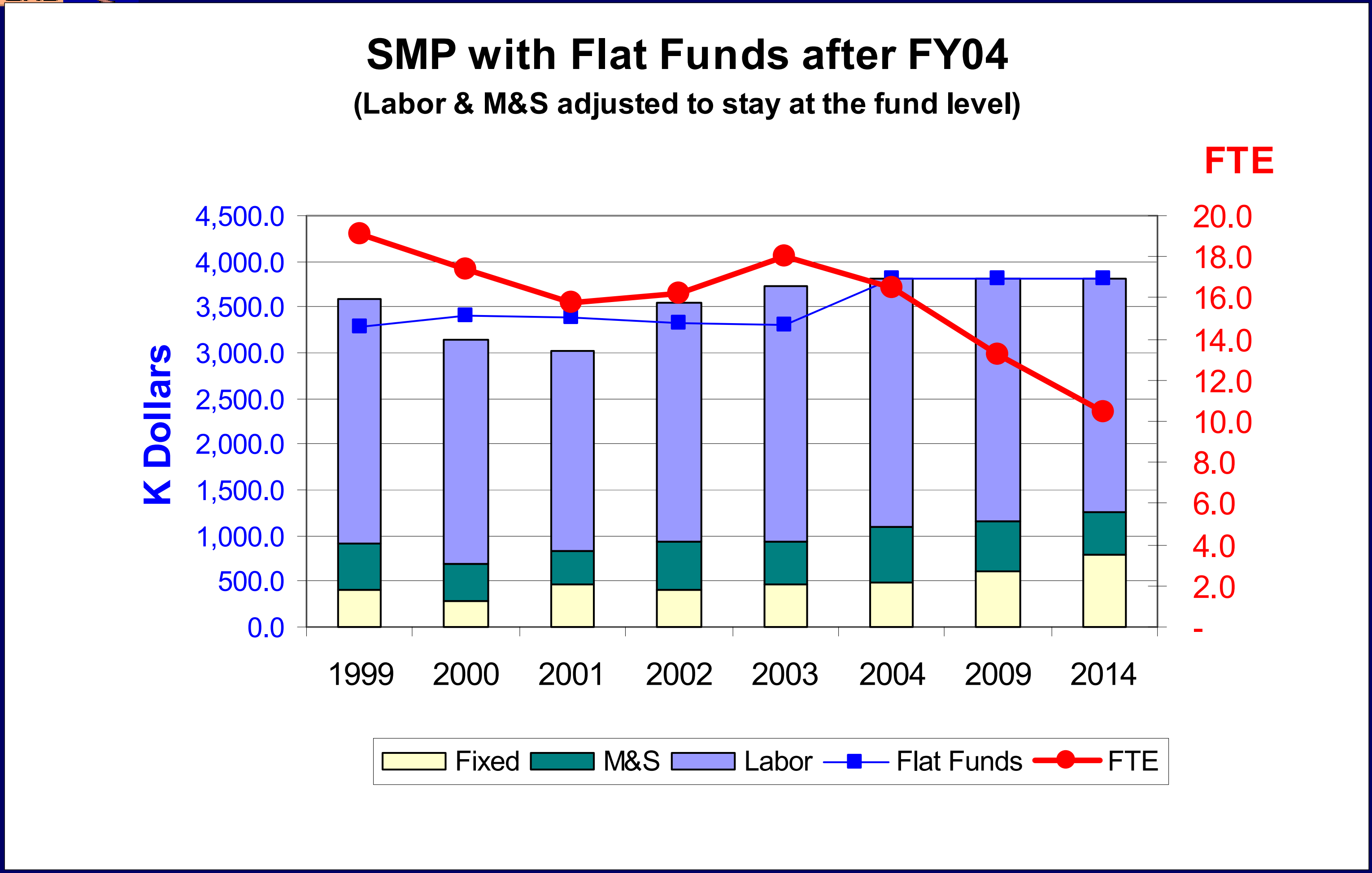
Budget and Staff Update

- Expecting a $500k increase for FY04
  - Test Facility improvements
- Test facility staff augmented
  - Mark Nyman (EE)
  - Bill Lau (E-tech)

Still some problems due to flat-flat budget history

- Priorities
  - Maintain staff
  - Maintain productivity
- Shift effort to Sub-Scale Magnet program
  - Focus on large models as resources allow
- Bring in outside work
  - Bi-2212 Cable for Showa
  - GSI
  - Fusion – HCX quad tests

Funding Projection



BERKELEY LAB

LBNL Superconducting Magnet Program

- Extensive expertise in application of Nb_3Sn to high field magnets
  - Apply proven LBNL technology
    - First HEP application of Nb_3Sn will be for LHC upgrades
    - Applications in other fields
    - Future HEP Projects
  - Develop and maintain the largest set of HEP options
- DOE has set ambitious goals for the program
  - Supported by significant funding increase in FY04

Summary

- Program is making steady progress
  - HD1 – New dipole field record on the horizon
  - We are now well into the new Sub-scale magnet test program
    - Completed 4 tests since last review
    - Four more next year
  - DOE/HEP Conductor Development Program continues to show excellent progress
- Some Issues
  - Staff
    - We have assembled an excellent team – need to maintain it!
  - Funding
    - Looking up – but still need to augment with other work

Superconducting Magnet Program

Program Office

S. Gourlay (Program Head)

R. Scanlan (Deputy)

K. Weber (Administrative Assistant)
M. Barry (Budget Analyst)
S. Buckley (Admin)

EH&S

N. Liggins, K. Weber (Coordinators)

QA/Documentation

R. Hafalia (Coordinator)

Advisory Committee

G. Sabbi (Chairman)
Science and Engineering Staff

SC Materials and Cable Development

R. Scanlan (Leader)

SC Magnet Development

S. Gourlay (Leader)

Matrixed Projects

A. Lietzke (Coordinator)

Technical Staff

- Technicians
  - P. Bish
  - M. Goli
  - R. Hannaford – Magnet Fabrication
  - H. Higley
  - B. Lau
  - N. Liggins
  - J. Swanson
- Engineering/Design Staff
  - S. Bartlett (ME)
  - S. Caspi (ME) – Magnet Design
  - P. Ferracin (ME Post-Doc)
  - R. Hafalia (ME)
  - R. Hinkins (Retiree)
  - M. Nyman (EE)
- Scientific Staff
  - L. Chiesa
  - D. Dietderich
  - S. Gourlay
  - A. Lietzke – Test Facility
  - A. McInturff (1/2)
  - G. Sabbi (1/2)
  - R. Scanlan
- Administrative Support
  - M. Barry (1/8)
  - S. Buckley (1/8)
  - J. Smithwick (1/4)
  - K. Weber
- Students
  - B. Byer (UCB)
  - K. Molnar (UCB)